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Third Semi-Annual Report

A Fundamental and Feasibility Study of Ring-Vortex Gaseous-Core Cavity Reactor

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I. INTRODUCTION

This is the third semi-annual report (from February 1 to July 31, 1965) on the Fundamental and Feasibility Study of Ring-Vortex Gaseous-Core Cavity Reactors under Grant No. NsG 586. Reference should be made to the statements in the last two semi-annual progress reports to which this report is a continuation.

The experimental work is summarized in Part II and the theoretical study is outlined in Part III. For your information, the following reports under NsG 586 have been sent to the Office of Grants and Research Contracts, NASA:

Technical Rept. No.	Title	Date Submitted
65-001	Stability of Two-Layer Viscous Stratified Flow Down an Inclined Plane	2/4/65 Rec'd
65-002	Magnetohydrodynamic Boundary Layer Between Parallel Streams of Different Magnetic Fields and Temperatures	2/4/65 Rec'd
65-003	Stability of a Shear Flow in an Unstable Layer	2/4/65 Rec'd
64-005	On the Establishment of Density Profile for the Flow of a Two-Fluid Single Phase Gas Mixture	4/9/65 Rec'd
65-006	The Stability of Swirling Flow of a Viscous Conducting Fluid in the Presence of a Circular Magnetic Field	6/14/65 Rec'd

According to Mr. R.G. Ragsdale of Lewis Research Center, Reports [illegible] and 65-005 will be published at Lewis and further distribution will be made from [illegible]. Report No. 65-006 also was submitted to the Journal of Physics of Fluids for publication. Report No. 65-001 is already published in the May 1965 issue of Journal of Physics of Fluids. Report No. 65-002 also has been submitted to the AIAA Journal for [illegible] and is in revision.

In the next few months, a number of reports will be completed and [illegible] to the Office of Grants and Research Contracts, NASA. Some of the details [illegible] reports will be stated in this progress report.

II. EXPERIMENTS

As reported in the second annual report on the two-phase flow experiments with high injected velocity and density increment ratio $\rho_2 - \rho_1 / \rho_1 > 1$, the heavier fluid rotates near the outer circular wall to compete with injected faster lighter fluid on account of centrifugal effect. Hot lighter fluid maintains in the center core and whirls with outer heavier fluid like a solid body rotation. Another important fact is that turbulent diffusion between heavy and light gases (bromine-helium) is so strong that short transient action period of centrifugal force which is produced by means of reverse curvature is not enough to separate the heavy fluid from the light fluid and it is difficult to confine the heavy fluid without drifting away together with the escaping light fluid. This means that the observed good confinement of solid heavy particles in the system of rotating water where the injection and ejection are in two opposite tangent directions does not apply to the two-phase fluid mixture of the same model system.

In liquid, the axial positions of solid heavy particles can be controlled fairly well with two end jets in the cylindrical model. However, further experiments should be carried out for the case with two-phase gas flow particularly with $\rho_2 - \rho_1 / \rho_1 > 1$, and the good features on stopping the loss of heavy medium observed with the end jets should be further carefully verified. With strong inward radial injection of water in the cylindrical model, the heavy particles can be pushed inward and free from the end wall. This interesting feature can be demonstrated well in laboratory experiments. In the near future, the same phenomena will be verified with two phase fluids.

1. Cylindrical Cavity Model

By using end wall jet streams we have successfully forced heavy particles to circulate and concentrate in a ring suspended within the lighter propellant fluid and can keep the heavy particles away from the end wall. Consequently, heavy particles were trapped completely inside the cavity without being carried away by the center [illegible] flow of light fluid. Our study is based on using water as the light propellant fluid and heavy particles used are sand, iron, and glass beads. We have made measurements on the static pressure distribution of the entire cylindrical cavity to arrive at the conclusion that the ring of heavy particles are suspended in the low pressure region formed by the two opposite located jet streams. This ring of particles is kept away by centrifugal force from the vortex core so that they do not drift away with the light exhaust water. The object of our experiments is to force this ring of heavy particles away from the side wall of the cavity to be wholly suspended in the lighter fluid yet particles in its inner diameter can maintain sufficient distance from the [illegible] core. Radial flow from side wall of the cylinder was introduced to achieve [illegible]. Various methods of introducing radial flow were tried for obtaining best results. [illegible] ring of particles under the influence of radial flow will spread across the [illegible] of the cavity with finer particles close to the vortex core and coarse particles adjacent to the side wall at the periphery of the ring. Tracer oil droplets with the same density as water are injected with the radial flow from the sidewall to determine the resident time and flow pattern so as to know whether there is enough time for mixing to execute proper heat exchange between cold propellant fluid and hot gaseous fuel in the actual case. Because the flow from jet streams are essentially turbulent, plus the fact that high rate of secondary up-and-down flow existed in the vortex flow field, flow mixing seems to be quite well established. Exact resident time for in-coming flow at different locations will be determined by photographic means, when a new model suitable for this purpose is completed. Currently, a gaseous core cylindrical model of two gases is in development to explore more realistic physical features.

2. Toroidal Cavity Model

Since in toroidal cavity there are no end walls, the loss of heavy fluid through end wall boundary layer will not occur. If efficient cooling method could be developed to cool the walls, toroidal shape gaseous core cavity has its inherent advantages for being used as a propulsion device due to its favorable geometrical feature. In the past few months, several attempts to make the model from glass resulted in failures as the glass model is extremely fragile and difficult to fabricate. Finally, a stainless steel model with a tubular cross-section six inches in diameter has been made. Four jets with adjustable inlet angle will be added to this model. Adjustable depth exhaust nozzles, slit light and viewing lens are in construction for flow pattern study. The model should be ready in a few months.

Gas analysis made by a Perkin-Elmer Gas Chromatograph to study the trapping of heavy gas Freon-12 in the flow field of helium gas for a two dimensional model reveals the fact that trapping of heavy gas is satisfactory but not very efficient as the layer of heavy gas circulating along the boundary secondary flow of the side wall will travel through the end wall boundary layer and escape through the exhaust nozzle. Now another two dimensional model is being made with end wall jet stream incorporated to offset the end wall boundary layer effect.

III THEORETICAL STUDY

1. General Theoretical Approach

In this program when any new experimental phenomena is discovered, a discussion among members of the whole group is immediately held and usually stimulates some new ideas and physical insight into a problem. Then some simplified mathematical model can be formulated and mathematical treatment will begin. In other words, we try to develop some simple theories to fit the needs of the experiments.

In the present program, two phase fluid flow of density ratio is essential to the problem. Three dimensional configuration, centrifugal force, mass transfer, heat transfer, magnetohydrodynamic effects, instability and bouyance force all are also very important features in the present phase of study. However, each of the above features is a difficult subject to analyze in fluid mechanics and heat transfer. Therefore, because of the complexity of the problem, theoretical results cannot be achieved in a short time.

In the present program, we try to single out and simplify some important features of the experimental problems which can be treated analytically. Some analytic results then obtained can improve the understanding and also stimulate further experimental study.

2. Stability Study

A study of the stability of a swirling flow in a circular magnetic field has been made and the stability criterion is established. A rather striking phenomenon is that there is a case in which the unstable circulatory flow field is counterbalanced by the unstable circular magnetic field such that the combined field makes a stable flow. The general analysis and detailed calculations are contained in Technical Report No. 65-006.

(a) "The Stability of Swirling Flow of a Viscous Conducting Fluid in the Presence of a Circular Magnetic Field," by Hsien Ping Pao, Technical Report No. 65-006, Department of Space Science and Applied Physics, The Catholic University of America, May 1965. A sufficient condition for the stability of a swirling flow in a circular magnetic field is established. A stronger sufficient condition for stability is also given on physical grounds and by an approximate mathematical proof. Detailed results for small spacing between the cylinders are given. It is shown that the stronger sufficient condition for stability is exact for small spacings. A new branch of solution which corresponds to negative critical Taylor number is calculated.

An approximate solution for a particular case is also given. A rather striking phenomenon is that there is a case which the unstable circulatory flow is counterbalanced by the unstable circular magnetic field such that the combined field makes a stable flow. The dual roles of viscosity and magnetic diffusivity and their physical mechanism are also discussed.

(b) "The Stability of Viscous Conducting Swirling Flow in the Presence of a Circular Magnetic Field and a Radial Density Gradient," by Hsien Ping Pao, Technical Report, Department of Space Science and Applied Physics, The Catholic University of America. (In preparation - to be completed in 4-5 weeks.) The stability of an electrically and thermally conducting swirling flow in the presence of a radial temperature gradient, as well as a circular magnetic field, is studied. Sufficient conditions for stability are established. Detailed results for small spacing between the cylinders are given. New branches of solution which correspond to negative Taylor number are calculated. The conjugate relationship between different branches of solution is revealed and discussed. The roles of three diffusive coefficients, momentum, magnetic, and thermal diffusivities, are discussed. It is found that the viscosity (momentum diffusivity) plays a dual role and has dual effect, the magnetic diffusivity plays a single role with dual effect, and the thermal diffusivity plays a single role with single effect.

(c) Stability in Stratified Gas Flow. In the cavity reactor the problem of the stability of a heavy, hot gas (uranium) supported by a light, cold gas (hydrogen) which is injected at the wall is important. We investigate a two layer model in which the gases obey equations of state such that density is proportional to temperature. The temperature distribution then implies a stable density stratification in each layer. Combined with the density profile and gravity we have a velocity profile U(Z) of the jet type. In the inviscid limit the velocity profile is expected to be of the stable type. Thus the stabilizing effect of the velocity and of the stratification within each layer is combined with the destabilizing effect of the density discontinuity at the interface of the layers. In general, the configuration is unstable, and we wish to determine the largest instabilities and the scale of the motion associated with them. This work has just been started.

3. Density Profile and Suction in Mixed Flow

Continued study on the establishment of density profile for the flow of a two-fluid single phase gas mixture has been undertaken. A theory is developed for the case of swirling flow with the body force provided by the centrifugal action of the swirl. Solutions are given for a large class of swirling motions including motions with reverse flow. Asymptotic forms of the density profiles are explicitly calculated. A "singular" perturbation scheme is used to give the orders of the higher order correction terms in terms of the reciprocal of a diffusive Reynolds number, and the uniform validity of the zeroth order solution is established. A final report on this subject is being prepared.

Study is also being made on the theoretical determination of the composition of the fluid withdrawn from the cavity reactor to assess what is the percentage of fuel that is lost if the concentration profile of the fuel is established according to the theory mentioned in the last paragraph. A technical report is in preparation.

4. Radiation Heat Transfer Between Two Parallel Streams of Optically Thick Flows.

The radiation heat transfer between two parallel streams of optically thick flows is studied. In order to investigate the main features of the radiation heat transfer, this study is carried out by assuming that the two parallel streams are incompressible and inviscid. The radiation slip boundary condition and a matching procedure between the optically thin and optically thick regimes proposed by [illegible] are used. The exact solution of the problem is obtained in a closed form. [illegible] shows a smooth transition regime in optically thick flows between the black body [illegible] lation and the Rosseland diffusion formulation. Numerical calculations are being [illegible] out and a final report of this investigation will be ready by September 19[illegible].